Achieving the 2050 Greenhouse Gas Reduction Goal

How Far Can We Reach with Energy Efficiency?

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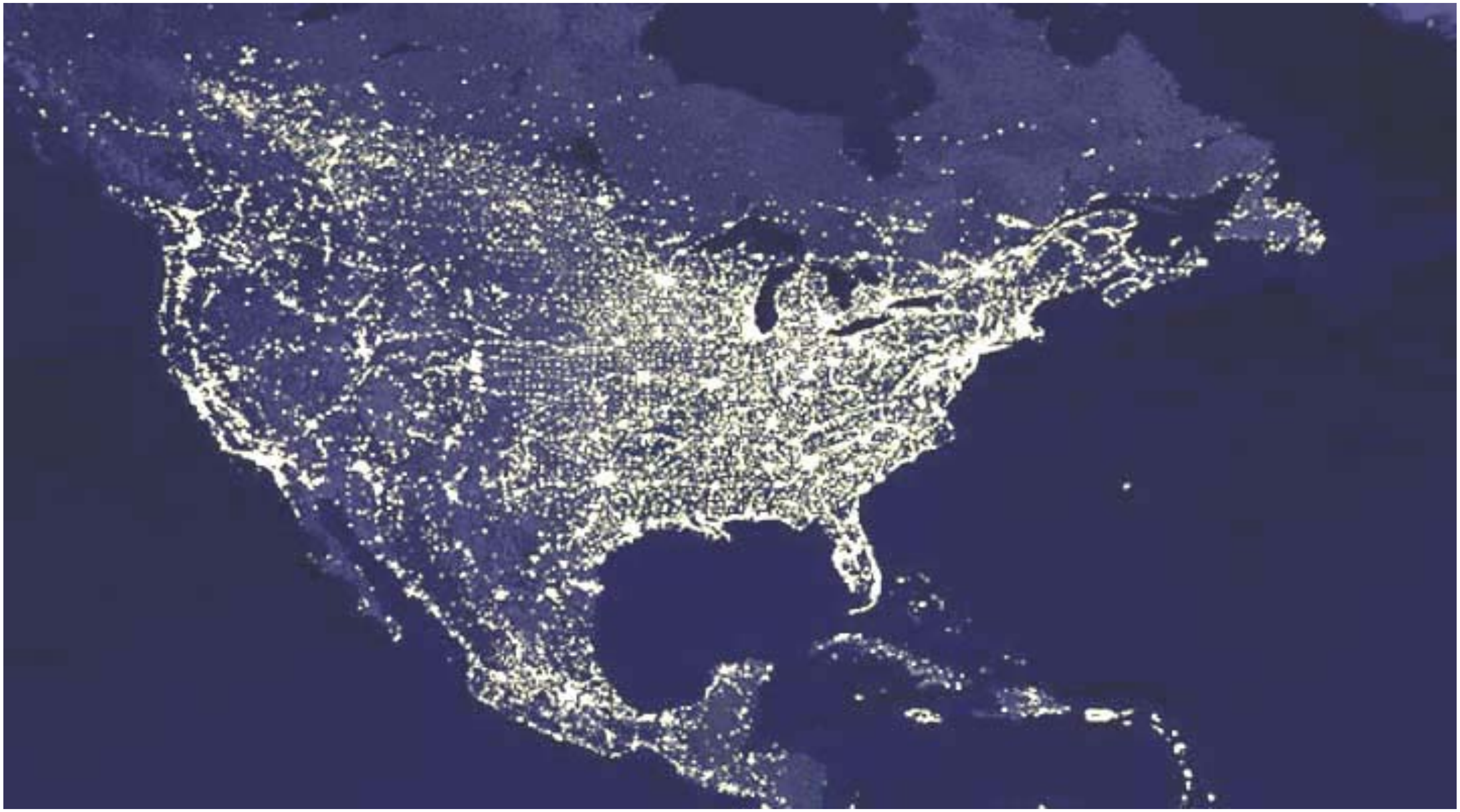
or just Google "Art Rosenfeld"

Introduction

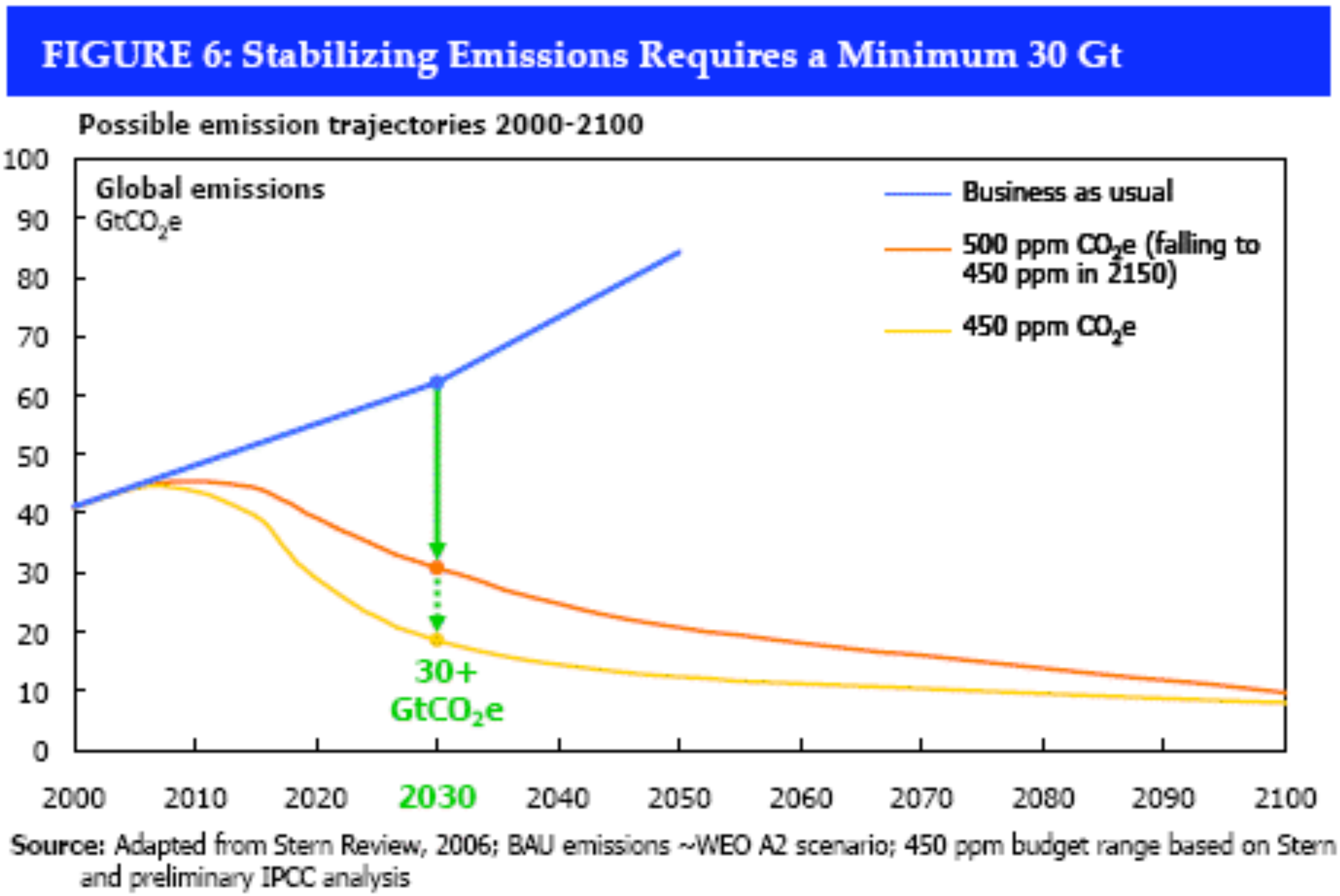
- Focus will be on 2030 as my crystal ball is hazy after that
- Will the world find motivation to reduce CO2?
  - Hurricanes (more frequent, further North), Fall fires and droughts
- The UN or a "super-G8" must cooperate in this effort
  - With financial incentives for China, India, … for "clean" coal.
- Cap and Trade systems will probably not be sufficient to keep levels at 450 ppm or below
- To modify behavior (e.g. land use, travel) switch to a Carbon Tax where you can tax "bads" to pay for "goods" (e.g. social security or medical insurance)
  - ~$3/gallon of gasoline, ~$300/ton of CO2, or ~20 cents/kWh
- "Free Trade" for lower carbon fuels. e.g
  - Elimination of $0.50 per gallon on imported ethanol

Illuminating Space vs. the Street



To maintain 50/50 chance of staying below 2°C implies stabilizing <450ppm GtCO2e
(*at least* 30 Gt reduction by 2030)

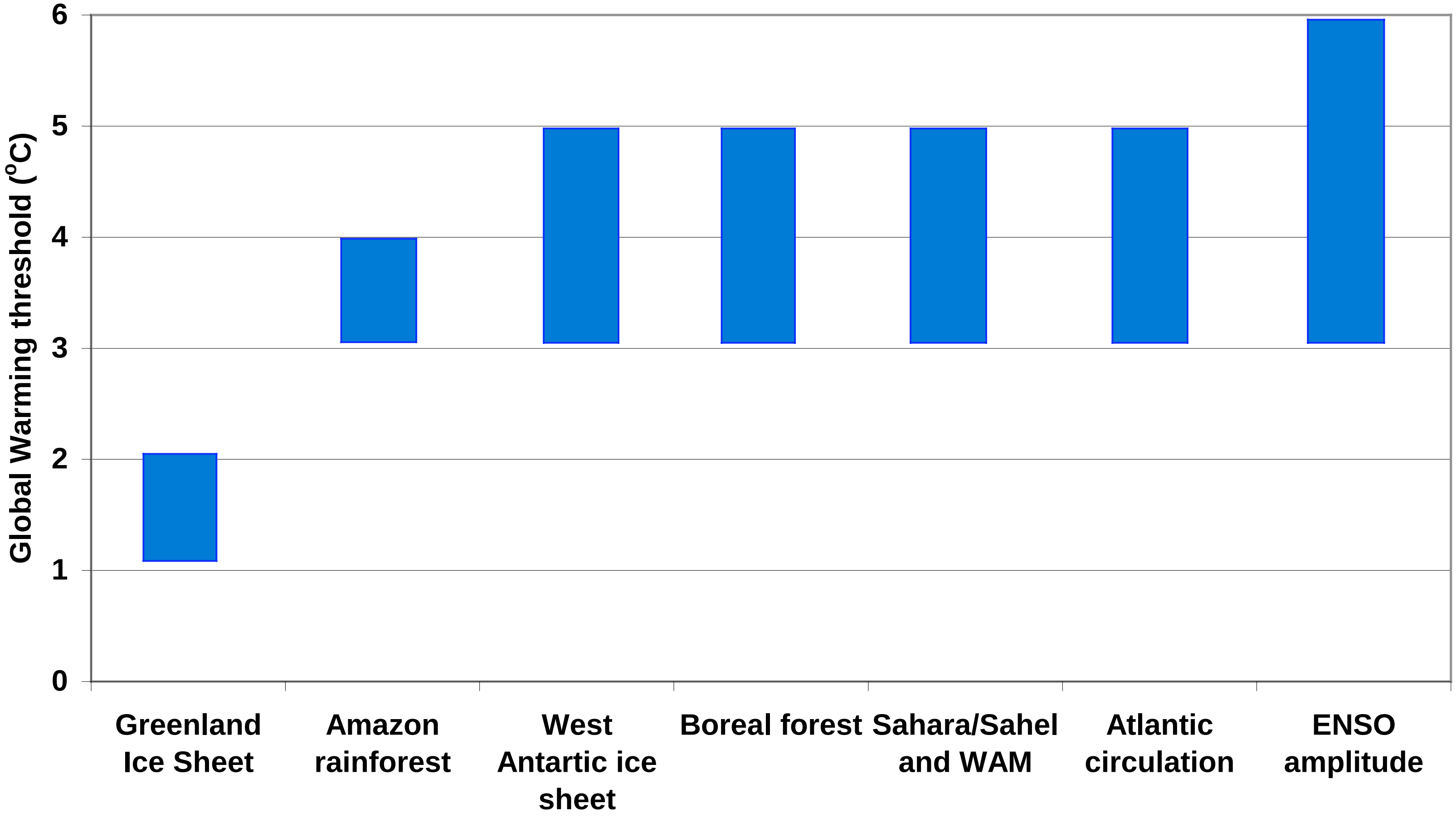
Possible emission trajectories 2000-2100 of global Emissions: from Hal Harvey, “Design to Win,” California Environmental Associates, **adapted from Stern Review**



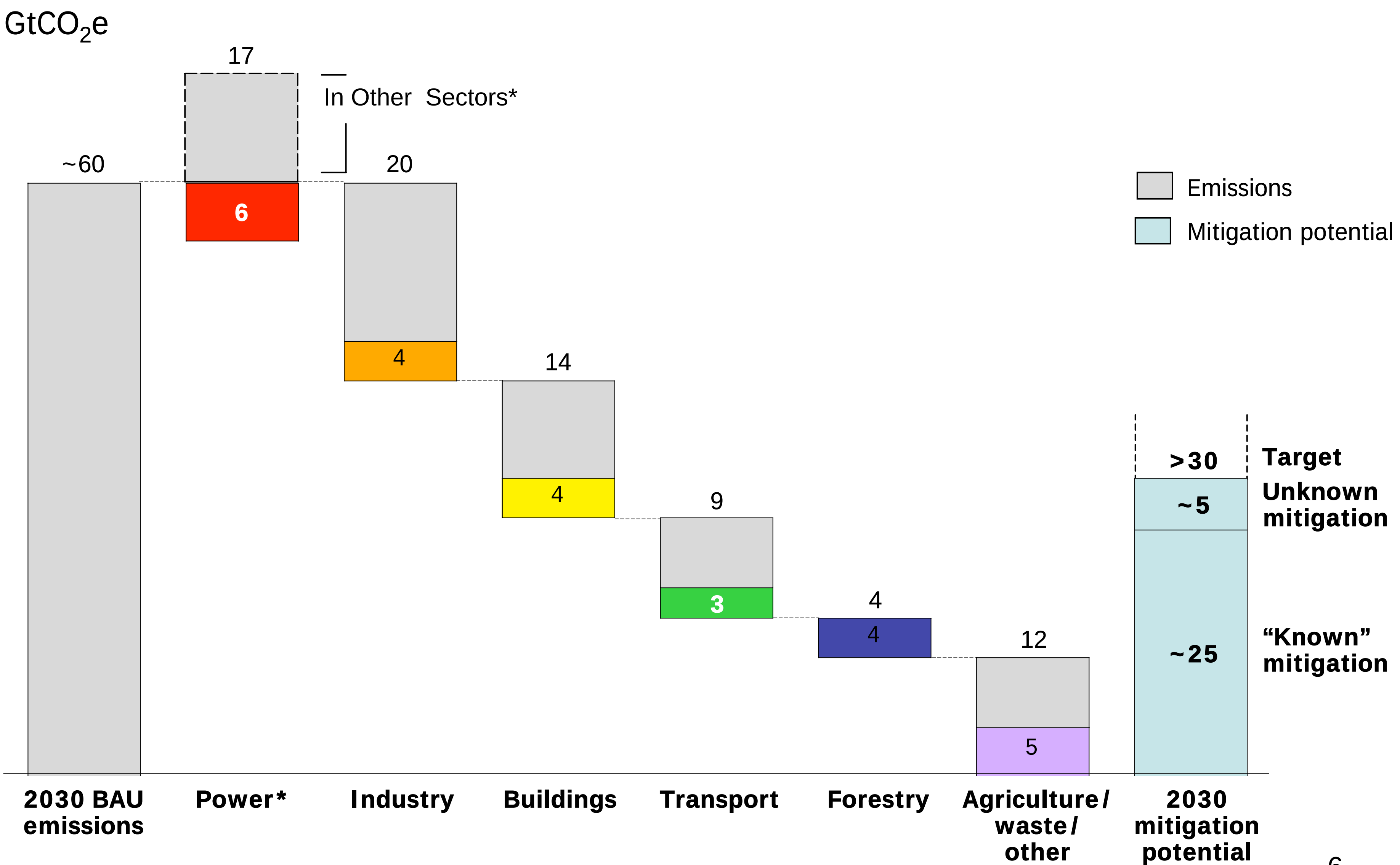
http://www.climateactionproject.com/docs/Design_to_Win_8_01_07.pdf

Tipping Element

(from Tipping Points of Gradual Climate Change, Timothy M. Lenton, U of East Anglia)



Available interventions in 6 sectors Worldwide could secure 5/6 of target based on *Design to Win*



* Power sector emissions (but not mitigation potential) counted in industry and building sectors

Conservation Supply Curves Explained

- Start with conservation supply curves for electricity, natural gas, gasoline, etc
- Annual benefit = yearly saved bills – annualized cost of measure
- Then convert kWh or therms or gallons or … to CO_2 avoided
- Note that shaded areas are dollars saved or spent (depending if below or above the x-axis)

See NAS “Policy Implications of Greenhouse Warming” 1992, App. B

- **Policy Implications of Greenhouse Warming**: Mitigation, Adaptation, and the Science Base (1992) Committee on Science, Engineering, and Public **Policy** (COSEPUP **...** books.nap.edu/books/0309043867/html

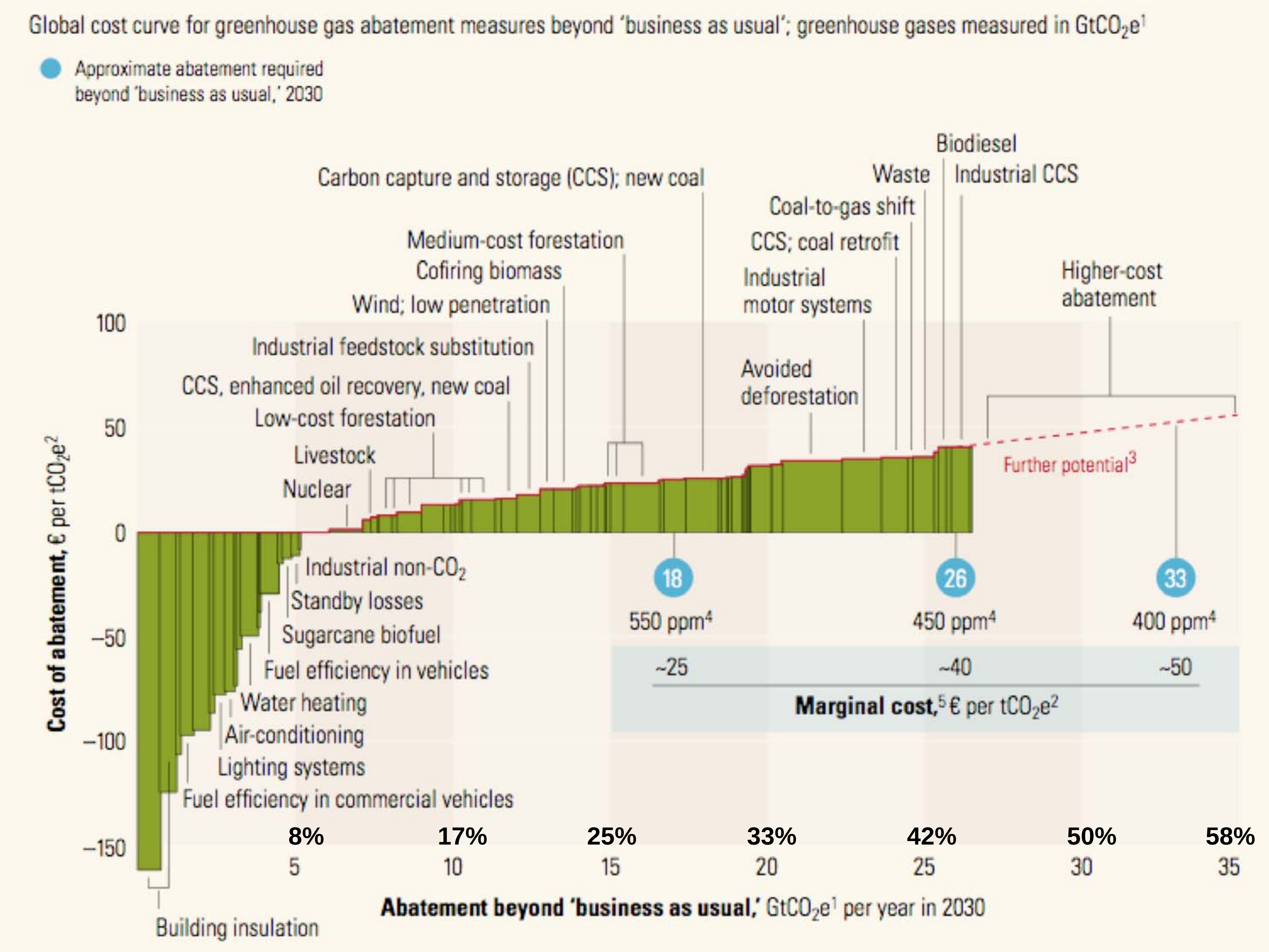
McKinsey Quarterly

A **cost curve** for greenhouse gas reduction

A global study of the size and cost of measures to reduce greenhouse gas emissions yields important insights for businesses and policy makers.

Per-Anders Enkvist, Tomas Nauclér, and Jerker Rosander

http://www.mckinseyquarterly.com/Energy_Resources_Materials/ A_cost_curve_for_greenhouse_gas_reduction_abstract



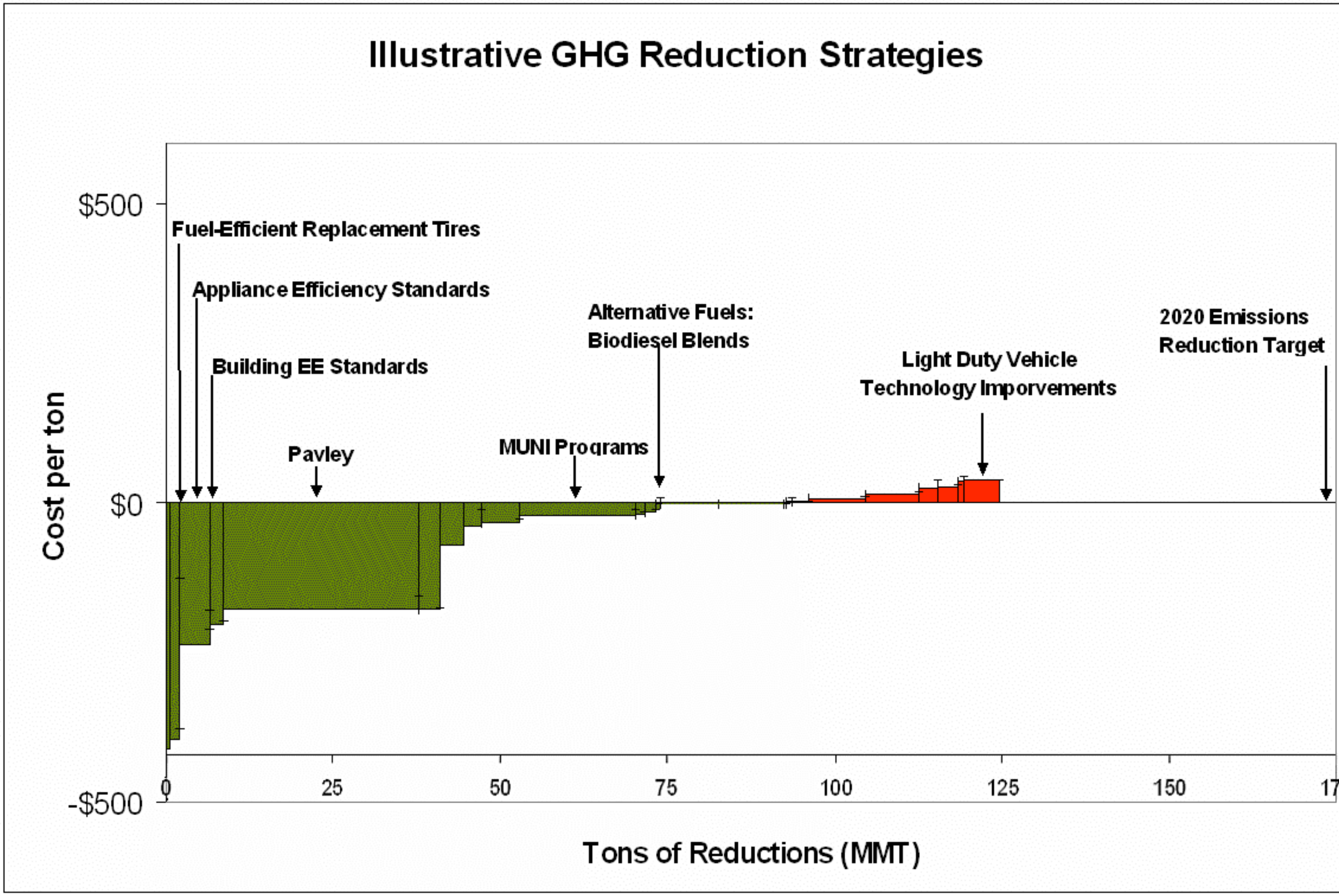
Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in GtCO2e1
Approximate abatement required beyond 'business as usual,' 2030
Cost of abatement, € per tCO2e2
100
50
0
−50
−100
−150
Biodiesel
Waste
Industrial CCS
Carbon capture and storage (CCS); new coal
Coal-to-gas shift
CCS; coal retrofit
Medium-cost forestation
Cofiring biomass
Industrial motor systems
Higher-cost abatement
Wind; low penetration
Industrial feedstock substitution
Avoided deforestation
CCS, enhanced oil recovery, new coal
Low-cost forestation
Livestock
Nuclear
Further potential3
Industrial non-CO2
Standby losses
Sugarcane biofuel
Fuel efficiency in vehicles
Water heating
Air-conditioning
Lighting systems
Fuel efficiency in commercial vehicles
Building insulation
18
550 ppm4
26
450 ppm4
33
400 ppm4
~25
~40
~50
Marginal cost,5 € per tCO2e2
8% 17% 25% 33% 42% 50% 58%
5 10 15 20 25 30 35
Abatement beyond 'business as usual,' GtCO2e1 per year in 2030

Turning to California

- AB 32 CO2 Goals:
  - 1990 levels by 2020
  - 80% below 1990 levels by 2050
- Where are we headed?

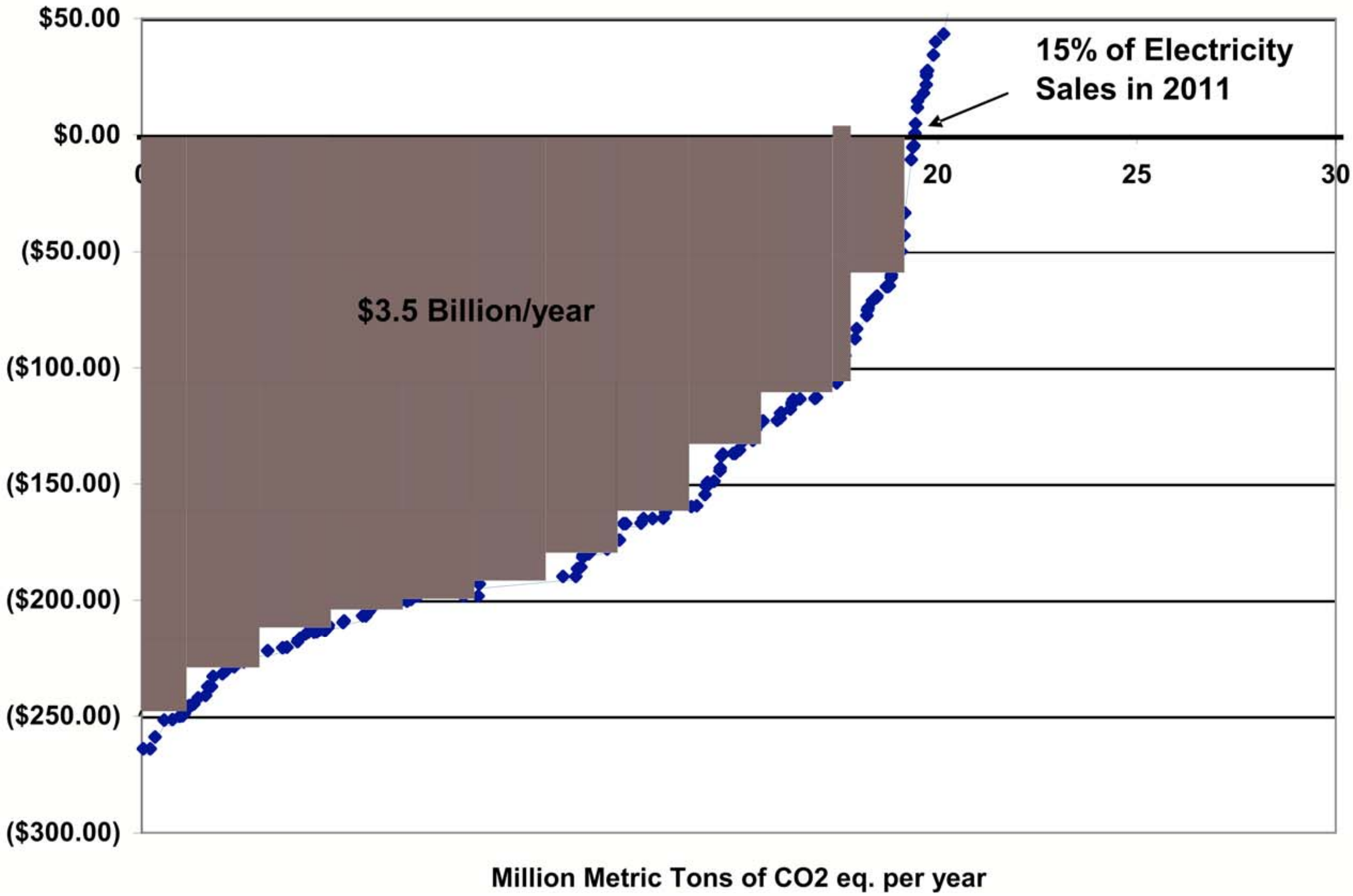
	1990	2000	2010	2020	2030	2040	2050
CALIFORNIA Population (million)	30	34	39	44	49	54	60
growth rate (historic and projected)		1.3%	1.4%	1.2%	1.1%	1.0%	0.9%
CO2 Business as Usual (MtCO2 eq.)	436	480	530	585	647	714	789
CO2 to Meet AB 32 Goals	436	480	486	436	320	204	87
growth rate to Meet AB 32		1%	0.1%	-1%	-5.3%	-5.3%	-5.3%

Note: CO2 historic and projected data continue to change, consider these as estimates



Illustrative GHG Reduction Strategies
$500
$0
-$500
Cost per ton
Fuel-Efficient Replacement Tires
Appliance Efficiency Standards
Building EE Standards
Pavley
MUNI Programs
Alternative Fuels:
Biodiesel Blends
Light Duty Vehicle
Technology Imporvements
2020 Emissions
Reduction Target
0
25
50
75
100
125
150
175
Tons of Reductions (MMT)

Supply Curve for CO2, Conserved thru Energy Efficiency in Electricity Sector in California - Potential in 2011 at 1 kwh = 0.454 kg of CO2



Cool Urban Surfaces and Global Warming

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White is ‘cool’ in Bermuda

and in Santorini, Greece

Cool Roof Technologies

Old

flat, white

pitched, white

New

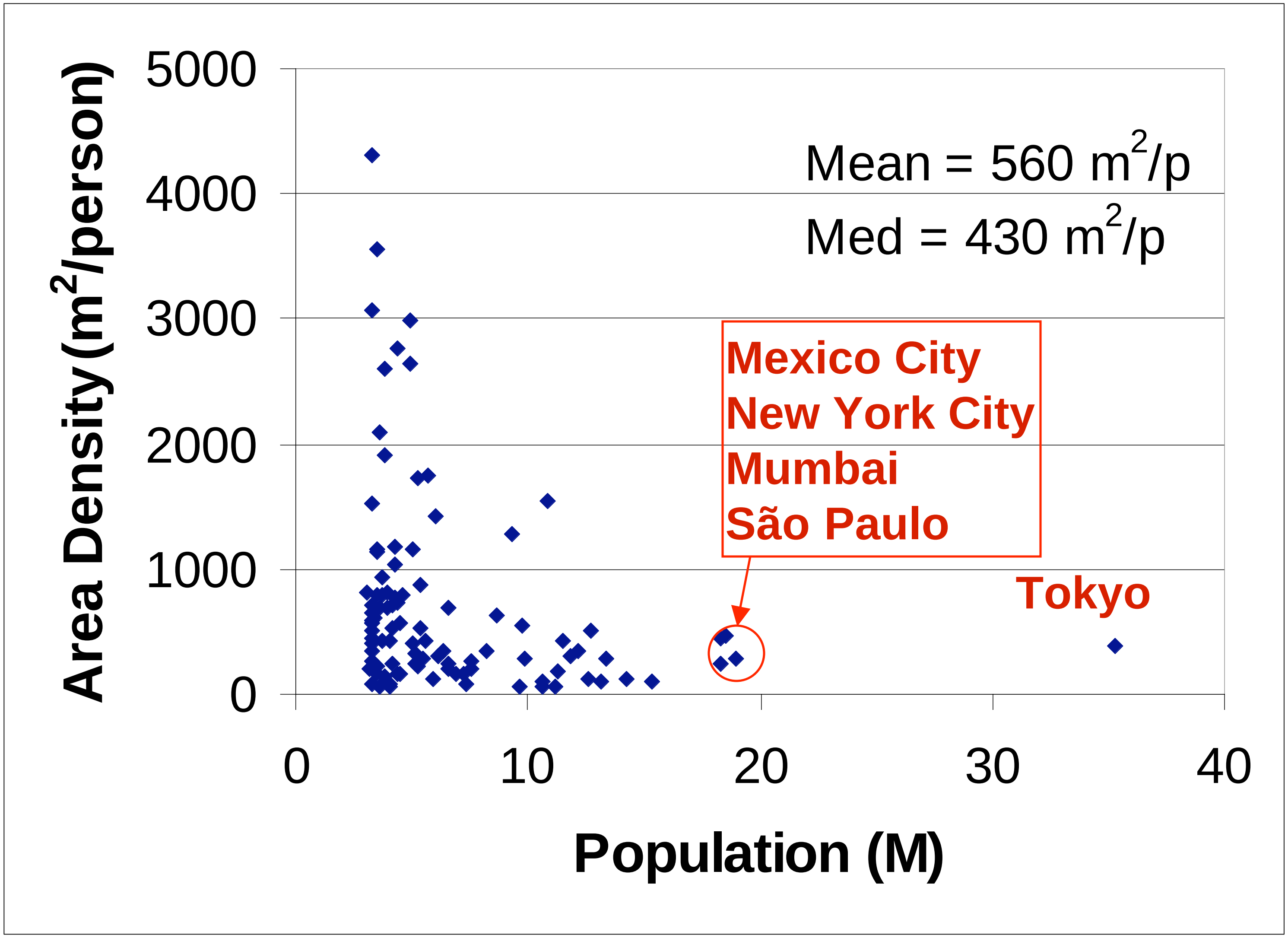
pitched, cool & colored

Cool Surfaces also Cool the Globe

- Cool roof standards are designed to reduce a/c demand, save money, and save emissions. In Los Angeles they will eventually save ~$100,000 per *hour*.

- But higher albedo surfaces (roofs and pavements) directly cool the world, quite independent of avoided CO_2. So we discuss the effect of cool surfaces for tropical, temperate cities.

100 Largest Cities have 670 M People



Radiative Forcing (RF) of 1 tCO_2.

- Myhre et al. (1998), for well mixed CO_2, quote

$$RF\ [W/m^2] = 5.35\ \mathit{ln}(1 + \Delta C/C).$$

Inserting $\Delta C = 1$ t CO_2, we find

$$RF(\text{worldwide}) \sim 1kW.$$

so, enough white roof to reflect 1 kW (on average, night, day, adjusted for clouds) will offset 1 ton of CO_2. "Enough" turns out to be 30 m2.

So each 200 m2 white roof offsets ~7 t CO_2.

Dense Urban Areas are 1% of Land

- Area of the Earth = 508×10^{12} m^2
- Land Area (29%) = 147×10^{12} m^2 [3]
- Area of the 100 largest cities = 0.38×10^{12} m^2 = 0.26% of Land Area for 670 M people
- Assuming 3B live in urban area, urban areas = [3000/670] x 0.26% = 1.2% of land
- But smaller cities have lower population density, hence, urban areas = 2% of land = 3×10^{12} m^2 [4]
- Dense, developed urban areas only 1% of land [5]

Potentials to Increase Urban Albedo is 0.1

- Typical urban area is 25% [6] roof and 35% [7] paved surfaces
- Roof albedo can increase by 0.25 for a net change of 0.25x0.25=0.063
- Paved surfaces albedo can increase by 0.15 for a net change of 0.35x0.15=0.052
- Net urban area albedo change at least 0.10

Effect of Increasing Urban Albedo by 0.1

- Roof area = 0.25 [6]*$1.5\text{x}10^{12}$ m^2 [5] = $3.8\text{x}10^{11}$ m^2 [8]
- Carbon reduction of cool roofs
  = 33 kg $CO2/m^2$ [1]* $3.8\text{x}10^{11}$ m^2 [8] = 12 GT CO2 [9]
- Paved area = 0.35 [7]*$1.5\text{x}10^{12}$ m^2 [5] = $5.3\text{x}10^{11}$ m^2 [10]
- Carbon reduction of cool pavement
  = 20 kg $CO2/m^2$ [2]*$3.8\text{x}10^{11}$ m^2 [10] = 7.5 GT CO2 [11]
- Carbon reduction of cool roofs and cool pavements
  = 20 GT CO2 [12]
- 20 GT CO2 is half of the annual world emission of 40 GT CO2eq --- a reprieve of 6 mo with NO emissions.

Cooler cities as a mirror

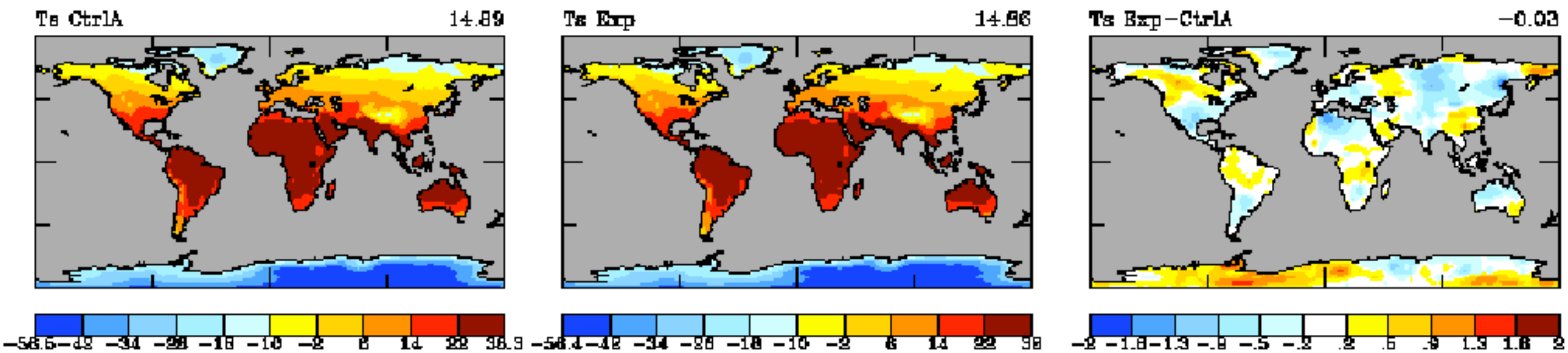
- Mirror Area = $1.5\text{x}10^{12}$ m^2 [5] *(0.1/0.7)[δ albedo of cities/ δ albedo of mirror]
  = $0.2\text{x}10^{12}$ m^2 {This is equivalent to an square of 460 km on the side}

Equivalent Value of Avoided CO_2

- CO_2 currently trade at ~$25/ton
- 20 GT worth $500 billion, for changing albedo of roofs and paved surface
- Cooler roofs alone worth $300B
- Cooler roofs also save air conditioning (and provide comfort) worth five times $300B
- Let developed countries offer $1 million per large city in a developing country, to trigger a cool roof/pavement program in that city

Effect of Increasing Urban Albedo by 0.1 on Global Temperature is -0.01K

- Using Harte's equations (*Consider a Spherical Cow*, pages 166, 174), the change in air temperature in lowest 1.8 km = 0.011K
- Using Hansen et al. (1997), the change in air temperature is = 0.016K (checks Harte's)



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References

- Hansen et al. 1997: J Geophys Res, 102, D6(6831-6864)
- Myhre et al. 1998: Geophys Res Let, 25, 14(2715-2718)
- Harte 1988: *Consider a Spherical Cow*, pages 166, 174

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